

The University of Chicago

A QUANTITATIVE STUDY
OF CERTAIN PHASES OF F-TYPE
SPECTRA

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR
OF PHILOSOPHY

DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

1935

By

JOSEPH ALLEN HYNEK

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By J. A. HYNEK

ABSTRACT

Quantitative data are given concerning the behavior of a number of the more important lines in F spectra. These lines include members of many of the most important pairs used as luminosity criteria for the determination of spectroscopic parallaxes in the classical researches of the Mount Wilson Observatory. A discussion is given of the behavior of the various lines in each F subclass.

The sharp- and diffuse-line F stars.—A parameter (line width/line depth) is given as a measure of the diffuseness of the metallic lines exhibiting various degrees of rotational broadening. This parameter varies over a range of more than thirty times among stars of Draper type Fo.

A comparison of Harvard and Mount Wilson spectral types shows that practically all of the bright diffuse-line Fo stars have been moved over into class A by Mount Wilson. The mean Mount Wilson spectral type of the twenty-one most diffuse H.D. Fo spectra is A 5.6.

The intensities of Ca II K and of $H\delta$ in sharp- and diffuse-line Fo stars confirm the consistency of the Henry Draper classification; at type Fo there is no systematic difference in the intensities on passing from narrow- to broad-line stars. There is a tendency for the strong Fe I lines to be systematically fainter in the diffuse-line stars; it is possible, however, that this is due to systematic errors in measuring the equivalent widths.

The sharp drop in the number of rapidly rotating stars between Fo and F₅ is confirmed, and it is shown that the diffuse-line stars are distributed over a considerably smaller range of spectroscopic absolute magnitude than are those having sharp lines. For sharp-line Fo stars the range is approximately 5 mag.; for twenty-one of the most diffuse-line Fo stars it is 0.9 mag., the latter clustering about absolute magnitude +2.0. The effect is not so pronounced when trigonometric absolute magnitudes are used, and it is possible that the difference is a result of a systematic error in the determination of spectroscopic parallaxes for rapidly rotating stars.

The behavior of Ca II K and of $H\delta$ with changes in spectral type.—A brief quantitative discussion of some of the most prominent F-type classification criteria is given. Ca II K increases in intensity about 50 per cent from Fo to Go and $H\delta$ decreases 75 per cent in the same range. The ratio $\text{K}/H\delta$ increases from 0.7 at Fo to 3.8 at Go. Visual estimates of this ratio are usually given as considerably greater; this difference between measured and visual estimates is ascribed to the effect on the estimates of the Stark broadening of $H\delta$.

The behavior of the luminosity criteria.—Equivalent widths in approximately one hundred F stars are given for the individual lines of five line ratios which have been used in the determination of spectroscopic luminosities at Mount Wilson. A quantitative summary is given of the behavior of these line ratios with luminosity in the F subdivisions. At type F₅ the most sensitive criteria among those discussed are: $\text{Fe II}—\text{Fe I } 4233/\text{Fe I } 4235$ and $\text{Sc II } 4246/\text{Fe I } 4250$; at F₈: $\text{Fe I } 4071/\text{Sr II } 4077$ and $\text{Ti II}—\text{Zr II } 4161/\text{Mg I } 4167$; at Go: $\text{Fe I } 4071/\text{Sr II } 4077$ and $\text{Sr II } 4215/\text{Fe I } 4250$.

The variation of Ca I and Fe I with luminosity at F₈ and Go.—The lines $\text{Ca I } 4226$ and $\text{Fe I } 4045$ vary with luminosity in a peculiar manner at types F₈ and Go. Both lines are very strong at $M=+4.5$. They then decrease in intensity to $M=+3.3$. In the giants, however, both lines are strengthened with increasing luminosity. In the case of $\text{Ca I } 4226$ the intensity reaches a maximum and is identical in dwarfs ($M=+4.5$) and in the most luminous giants ($M=-3.5$). For intermediate luminosities the line has only one-third of its maximum intensity. Its range in equivalent width is from 1.5 to 0.5 Å.

A possible explanation of the phenomenon is given. In the dwarfs the expected negative absolute-magnitude effect is observed, owing to the depletion of *Ca* and *Fe* atoms in the neutral state caused by the lowered pressure in the stellar atmospheres. In the giants, however, the tremendously greater extent of the atmospheres and the strengthening of all lines counterbalances and masks the effect observed in the dwarfs.

The intermediate giants of type Go.—It is unlikely that the three Go stars η Pegasi, α Ursae Majoris, and β Leporis, which have been assigned spectroscopic absolute magnitudes around +0.5 at Mount Wilson, are less luminous than the ordinary Go giants. Their trigonometric parallaxes, as well as their spectroscopic luminosity criteria, fail to support the low luminosities found at Mount Wilson.

I. INTRODUCTION

1. As the determination of spectroscopic parallaxes of stars later than class A has reached a very satisfactory state of accuracy at the present time, it is of some importance to investigate quantitatively the criteria used in the determination of luminosities spectroscopically. The present investigation is concerned with a study of some of the more important standards of absolute magnitude in the stars of types Fo–Go. The classical work which has been in progress at the Mount Wilson Observatory for the last twenty years has been taken as the basis for discussion.

The problem of spectral classification is so intimately bound up with that of the determination of spectroscopic parallaxes that a discussion of either subject must of necessity include the other also. In addition, a quantitative discussion will be given of certain features of the classification of the F stars.

2. The observational material consists of 440 spectrograms of 201 stars brighter than visual magnitude 5.5 and situated north of declination -20° . The plates are of one-prism dispersion and were obtained at the Yerkes and the Perkins observatories; the scale of the spectrograms is approximately 25 Å/mm at $H\gamma$. The Yerkes and Perkins plates have almost identical dispersions and were obtained on similar emulsions, the spectrograms measured having been obtained on Eastman Hyper-Press and Eastman 40 plates. The total absorptions of a selected group of lines were measured in 56 of the stars, and estimated intensities for these and for 54 additional stars were calibrated by means of the measures. The spectra of the additional 91 stars had been obtained a number of years ago on a variety of emulsions, and as they were not usually calibrated and are not strictly comparable, they were used only in certain qualitative aspects of the work.

The spectrograms were calibrated with tube sensitometers. Although the calibration is not monochromatic, the plate contrast does not change appreciably over the range in wave-length included, and a comparison of plates taken on the Eastman 40 emulsion with those taken on the orthochromatic Hyper-Press emulsion showed that no sensible errors are introduced by the type of calibration employed.

Two microphotometers were used for the measurement of the plates: the first, that belonging to the Mendenhall Physical Laboratory of Ohio State University; the second, that of the Ryerson Physical Laboratory of the University of Chicago. Both are of the Moll type. In the case of the line $H\delta$, actual profiles were obtained for the determination of the total absorptions; a simplified method of reduction was used for the other lines. The total absorptions were computed from the measured bases and line depths on the assumption that the profiles are triangular in shape. It has been shown that no appreciable error is introduced by this simplification. The probable error of a single calibrated estimate of total absorption is approximately 10 per cent, except in the case of weak lines.

II. THE SHARP- AND DIFFUSE-LINE F STARS

3. Systems of spectral classification which are not based on the Henry Draper system are little utilized at the present time and will not be discussed. The Pickering-Fleming classification of 1890¹ laid the foundation for the system which was later refined and is now universally used. The detailed description of the classification of the F stars published by Miss Cannon² in 1900 has remained sensibly unchanged up to the present time, as far as classification from objective-prism spectra is concerned. During the last twenty years there have been, however, a number of reclassifications in connection with work on the determination of spectroscopic parallaxes, called forth mainly because of the use of increasingly higher dispersion. The principal reclassifications which have been made are those of Adams and his collaborators,³ of Abetti,⁴ and of Young and Harper.⁵ In all of these cases an attempt was made to adhere as closely as possible to the Henry Draper system.

¹ *H.A.*, 27, 1, 1890.

² *Ibid.*, 28, 146, 1900.

³ *Ap.J.*, 53, 13, 1921.

⁴ *Pub. Obs. Arcetri*, 41, 9, 1924; 42, 9, 1925.

⁵ *Dom. Ap. Obs.*, 3, 1, 1927.

Two systems of reclassification were used in the earlier Mount Wilson work. The so-called "measured" class was determined from ratios of intensities of $H\beta$ and $H\gamma$ to neighboring lines. As these ratios also have a pronounced absolute-magnitude effect in certain cases, their determination was later abandoned. The second system gives the so-called "estimated" classes. These were determined by comparison with typical spectra of the various subdivisions. The K line of $Ca\ II$, whose intensity ratio with respect to $H\delta$ is the principal Harvard criterion in the range A0-F5, was not available on Mount Wilson plates. For the A and F0 stars the Mount Wilson classification is based on the intensities of the metallic arc lines. If the strong $Fe\ I$ lines $\lambda\ 4325$ and $\lambda\ 4383$ were absent or very faint, the spectrum was considered to be of type A0. As the arc lines increased in intensity, the spectra were considered to belong to successively later subdivisions. An attempt at refinement was made by utilizing all the decimal subdivisions available. As the Mount Wilson classification of the A and early F stars depends on the visibility and absolute intensity of comparatively faint lines, a systematic difference in classification between stars having sharp and diffuse lines as compared with Harvard types might be expected. Such a difference has been found for the A stars by Lindblad⁶ and, for the B, A, and F stars by Miss Fairfield.⁷ Miss Fairfield has also shown that the Mount Wilson diffuse-line classification does not parallel the Henry Draper system. The reclassification by Abetti rests on standards determined at Mount Wilson and is, in general, similar to the Mount Wilson results. The Victoria criteria were the same as those given most weight at Harvard. As a consequence, it would be expected that the classification by Young and Harper would differ little from the Draper system. From the fact that considerably more stars have been included in the Mount Wilson investigations than in the other series of spectroscopic parallaxes, the discussion of the classification of the F stars will be concerned principally with the Harvard and Mount Wilson data.

4. The most striking dissimilarities in the appearance of the spectra of the early F stars are those due to differences in the widths of the lines of medium and low intensity. These differences have been

⁶ *Ap.J.*, 59, 305, 1924.

⁷ *H.C.*, 264, 1924.

shown by Struve, Shajn, and Elvey⁸ to be an effect of varying speeds of axial rotation of the stars. The line widths of all stars for which plates were available were estimated on an arbitrary scale of one to four, group IV including the stars having the broadest lines. The estimated widths were then calibrated from microphotometric measures of *Fe I* 4045 in 50 stars. The ratio of the line width in angstroms to the line depth in magnitudes (W/m) was taken as the most convenient parameter. Table I gives the mean values of (W/m) for the four

TABLE I

Estimated Width	Mean (W/m)	No. of Stars
I.....	3.0	23
II.....	5.1	14
III.....	8.9	8
IV.....	17.8	5

TABLE II

DRAPER CLASS	LINE CLASS			
	I	II	III	IV
F ₀	17	18	21	23
F ₅	23	22	3	1
F ₈	15	9	0	0

classes of estimated line widths. The range in extreme cases is more than thirty times.

Table II shows the distribution of the diffuse-line stars in Harvard classes F₀, F₅, and F₈. As there are only about one-fourth as many F₂ stars as those of type F₀ or F₅ among the bright stars classified at Harvard, class F₂ has not been included. It is apparent that the relative number of broad-line stars decreases rapidly with advancing spectral type. No diffuse-line stars have been observed in types F₈ and G₀. The rapid falling-off in distribution was also shown by Miss Westgate⁹ from visual measures of line widths.

⁸ *M.N.*, **89**, 222, 1929; *Ap. J.*, **70**, 141, 1929; *Ap. J.*, **72**, 1, 1930.

⁹ *Ibid.*, **79**, 357, 1934.

A comparison of the Harvard and Mount Wilson classifications of stars belonging to the four line classes is given in Table III. There is a pronounced systematic difference at type Fo in the Harvard and Mount Wilson classifications for sharp- and diffuse-line stars. Practically all the Harvard Fo stars of line width IV have been moved over into class A by Mount Wilson. There is a tendency in the same direction at F5, but the number of broad-line stars is very small.

5. In view of the marked systematic difference between the Harvard and Mount Wilson classifications at Fo, it is of interest to in-

TABLE III

Spectral Type (Harvard)	Line Class	Mean Spec- tral Type (Mount Wilson)	No. of Stars
Fo.....	I	F 1.2	16
	II	F 1.5	18
	III	A 8.2	20
	IV	A 5.6	21
F5.....	I	F 4.4	22
	II	F 4.1	22
	III	F 2.3	3
	IV	A 7.0	1
F8.....	I	F 7.0	13
	II	F 7.8	11
Go.....	I	G 0.7	19
	II	G 0.2	9

vestigate the behavior of $Ca\ II\ K$ and $H\delta$, the ratio of whose intensities is the most important Harvard standard of spectral type among the A and early F stars. Table IV gives the intensities of K as a function of Harvard spectral type and line class. It is apparent from the tabulated intensities that no appreciable systematic difference in the intensity of $Ca\ II\ K$ exists among stars of different line widths of the same Harvard class. This is a confirmation of the consistency of the Henry Draper classification for sharp- and diffuse-line stars.

The intensities of $H\delta$ are given in Table V. Measures of $H\delta$ are more uncertain than those of the K line because of the changing

shape of the profile as a result of Stark effect. There is also a real dependence of the intensity of $H\delta$ on luminosity. Table V shows, how-

TABLE IV
INTENSITIES OF $Ca\ II\ K$

Harvard Spectral Type	Line Class	Total Absorption (Angstroms)	No. of Stars
F0.....	I	5.1	9
	II	4.7	8
	III	5.2	7
	IV	5.4	6
F5.....	I	5.4	12
	II	5.2	8
	III	5.1	3
F8.....	I	6.9	10
	II	6.0	5
G0.....	I	7.0	13
	II	8.1	2

TABLE V
INTENSITIES OF $H\delta$

Harvard Spectral Type	Line Class	Total Absorption (Angstroms)	No. of Stars
F0.....	I	7.0	6
	II	7.0	4
	III	5.7	6
	IV	8.4	6
F5.....	I	4.1	6
	II	4.8	5
	III	6.4	3
F8.....	I	2.9	5
	II	3.3	1
G0.....	I	1.9	8

ever, that at type F0 (Harvard) there is no appreciable correlation of total absorption with line class. The mean of the diffuse-line classes III and IV is almost identical with that of the sharp classes I

and II. At type F5 there seems to be a tendency for the more diffuse-line stars to have higher intensities for $H\delta$. As the number of broad-line stars is very small at F5, this tendency should not be considered as definite. It can be concluded, therefore, that the behavior of $H\delta$ is also in agreement with the Harvard classification. As the Fe arc lines form one of the principal criteria of spectral type in the Mount Wilson classification of the A and F0 stars, it is of importance to investigate their behavior with respect to line width. Table VI gives the intensities of the unblended lines of the strong Fe I multiplet $a^3F-y^3F^o$ at H.D. class F0.

TABLE VI
INTENSITIES OF Fe I LINES
(H.D. Class F0)

LINE CLASS	INTENSITY (ANGSTROMS)				No. OF STARS
	λ 4045	λ 4063	λ 4071	λ 4132	
I.....	0.58	0.47	0.30	0.31	10
II.....	.59	.46	.20	.25	9
III.....	.42	.31	.32	.24	6
IV.....	0.36	0.30	0.24	0.17	5

The Fe I lines seem to be systematically weaker in the diffuse-line F0 stars than in those having sharp lines. If this effect is real, it would justify the placing of diffuse-line Draper F0 stars in class A by Mount Wilson. There is a possibility, however, that errors in the intensities due to systematically drawing in the continuous background too low on the microphotometer tracings increase with increasing diffuseness of the successive width classes. It should be noted that the determinations of the intensities of K and of $H\delta$ are affected little, if at all, by the varying degree of diffuseness so apparent in the weaker lines. It may therefore be stated that the results, in general, confirm the consistency of the Draper classification.

It is interesting to compare the distribution of sharp- and diffuse-line stars with absolute magnitude. Table VII shows the total range in spectroscopic absolute magnitude for the four groups of line widths in Harvard F0 stars, the only F class in which there is an abundance of diffuse-line stars.

Table VII shows clearly a progressive decrease in the range of spectroscopic luminosity with increasing diffuseness of lines in the Harvard F₀ stars. Trigonometric absolute magnitudes are not reliable for the early F giants, but indicate that the same phenomenon occurs, though in lesser degree, when the stars included in Table VII are plotted against luminosities determined trigonometrically. If the effect is considered real, then the small range in luminosity of the diffuse-line stars, and their strong preference for an absolute magnitude of about +2, remains unexplained. It seems more probable, however, that the extreme diffuseness of the lines in these stars makes estimation of the luminosity criteria very difficult, and that the effect noted might be considered as a systematic error in the assignment of spectroscopic absolute magnitudes.

TABLE VII

Line Class	High M	Low M	Range ΔM	No. of Stars
I.....	-2.0	+3.2	5.2	14
II.....	+0.2	3.3	3.5	18
III.....	+1.1	2.9	1.8	20
IV.....	+1.4	+2.3	0.9	21

Since the diffuse-line stars cannot be compared directly with those having sharp lines without danger of introducing systematic errors in the measures, it has been considered advisable to include only stars of line-width class I in the following discussion. This class comprises the stars in which no broadening of the spectral lines can be detected on one-prism plates.

III. THE BEHAVIOR OF $Ca\ II\ K$ AND OF $H\delta$ WITH CHANGES IN SPECTRAL TYPE

6. From the measured intensities of $Ca\ II\ K$ and of $H\delta$ a quantitative investigation of the behavior of these standards according to spectral type can be made. Table VIII gives the mean intensities of K and of $H\delta$ for Harvard classes F₀, F₅, F₈, and G₀. The number of stars in which each line was measured can be found by referring to Tables III and IV. K is approximately 50 per cent stronger, and $H\delta$ is about one-fourth as strong at G₀ as at F₀. The ratio $K/H\delta$ in-

creases from 0.7 at Fo to 3.8 at Go. The visual ratio at Fo is given by Miss Cannon as about 3.0.² The discrepancy is probably due to the different shape of the two lines. The broader wings of $H\delta$ do not influence estimated intensities of the line as much as their actual contribution to the total absorption would demand. Most of the change in the ratio $K/H\delta$ is due to the great decrease in intensity of $H\delta$ in the later subclasses.

TABLE VIII

DRAPER CLASS	TOTAL ABSORPTION (ANGSTROMS)		RATIO $K/H\delta$
	K	$H\delta$	
Fo.....	5.1	7.0	0.7
F5.....	5.3	4.8	1.1
F8.....	6.6	3.0	2.2
Go.....	7.2	1.9	3.8

TABLE IX

Ratio	Numerator	Denominator	Observatory
4071/4077.....	<i>Fe</i> I	<i>Sr</i> II	Mount Wilson, Norman Lockyer, Victoria
4161/4167.....	<i>Zr</i> II, <i>Ti</i> II	<i>Mg</i> I	Mount Wilson, Victoria
4215/4250.....	<i>Sr</i> II	<i>Fe</i> I	Mount Wilson, Victoria, Norman Lockyer
4233/4236.....	<i>Fe</i> II, <i>Fe</i> I	<i>Fe</i> I	Mount Wilson
4246/4250.....	<i>Sc</i> II, <i>Fe</i> I	<i>Fe</i> I	Victoria

IV. THE BEHAVIOR OF THE LUMINOSITY CRITERIA

7. The individual components of five of the most important line ratios which have been used to determine spectroscopic parallaxes among the F-type stars were selected for quantitative investigation. The line ratios investigated are listed in Table IX.

The intensities of ten individual lines are listed in Table X as a function of spectral type.

The *Fe* I lines increase gradually and fairly uniformly in intensity on passing to stars of lower temperatures. The mean intensity of λ 4250 at Go is possibly an exception. The ultimate *Sr* II doublet

$\lambda 4077$ and $\lambda 4215$ also increases gradually in intensity in the later subdivisions. There is some evidence that the rate of increase in intensity with decreasing temperature is greater in the case of $\lambda 4215$. The blended line at $\lambda 4161$, which is due almost equally to $Zr II$ and to $Ti II$, shows little change with temperature. The line at $\lambda 4226$, which is due principally to $Ca I$, shows a marked increase in intensity in successively later spectral subdivisions. There is no appreciable change in $Sc II 4246$ with changing temperature. $\lambda 4233$ is due principally to $Fe II$ in the early F stars and about equally to $Fe I$ and $Fe II$ at F8 and G0. $Fe I 4235$ increases in intensity uniformly through successively later subdivisions. The lines least af-

TABLE X

DRAPER CLASS	INTENSITY IN ANGSTROMS									
	4071	4077	4161	4167	4215	4226	4233	4236	4246	4250
F0.....	0.31	0.51	0.28	0.32	0.46	0.54	0.38	0.28	0.30	0.32
F5.....	.44	.51	.35	.32	.50	0.66	.44	.34	.37	.35
F8.....	.53	.60	.39	.37	.65	1.02	.58	.46	.44	.48
G0.....	0.63	0.63	0.35	0.44	0.79	1.21	0.55	0.51	0.32	0.39

fected by changes in temperature are $Sr II 4077$, $Mg I 4167$, and $Sc II 4246$.

8. The behavior of the lines with respect to changes in luminosity is shown in Figures 2-6, in which the total absorptions are plotted against luminosities as determined from trigonometric parallaxes taken from the new *Yale Catalogue*. In the case of definite supergiants, such as ϵ Aurigae, φ Cassiopeiae, γ Cygni, and δ Canis Majoris, an absolute magnitude of -4 has been assumed. For other giants whose trigonometric parallaxes are insensible a parallax of 0.008 was assumed.

a) $Fe I 4071:Sr II 4077$ (Fig. 1)

There is no very marked absolute magnitude effect for $Fe I 4071$ at any place among the F stars. It is possible that the line is slightly strengthened on passing from dwarfs to giants at type G0. The remarkably high intensity of $Sr II 4077$ in certain F0 dwarfs such as

γ Equulei is abnormal, as there is a definite increase in intensity in most giants as compared with the dwarfs. There is a uniform in-

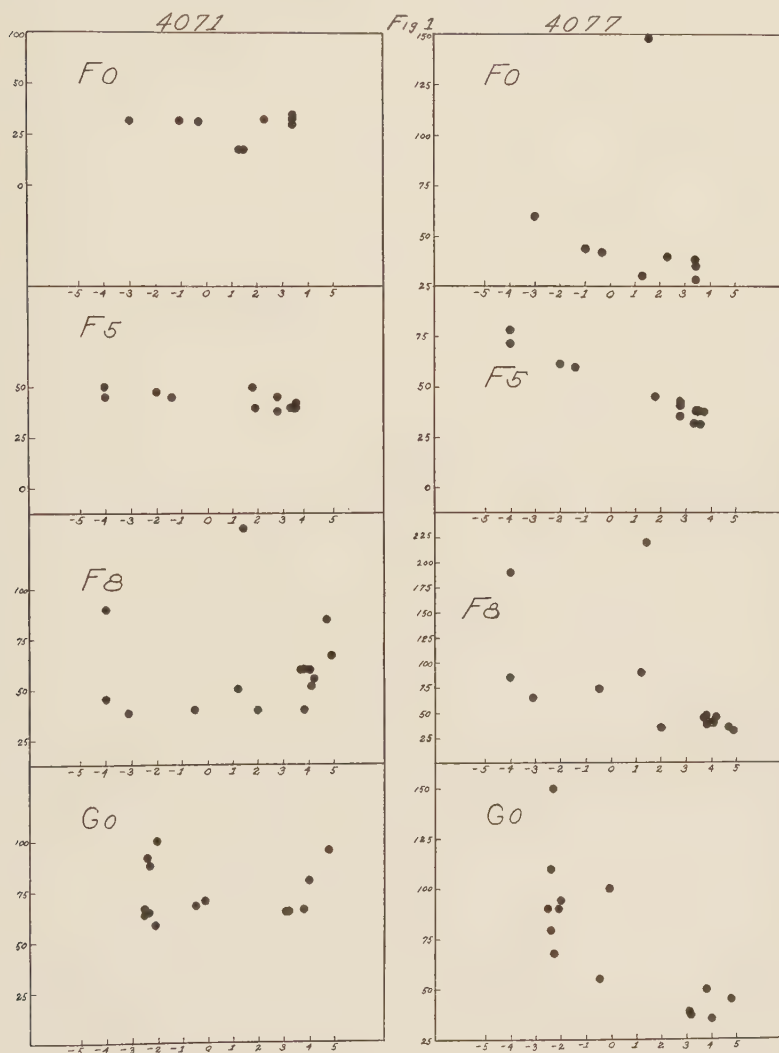


FIG. 1.—Intensities of Fe I 4071 and Sr II 4077. Abscissas are absolute magnitudes; ordinates are equivalent widths in units of 0.01 Å.

crease in the intensity of λ 4077 on passing toward the more luminous stars in classes F5, F8, and G0. The two discordant points at

class F8 refer to ρ Cassiopeiae and π Puppis. All details of their spectra point toward very high luminosity, but each star has a rather definitely determined trigonometric parallax.

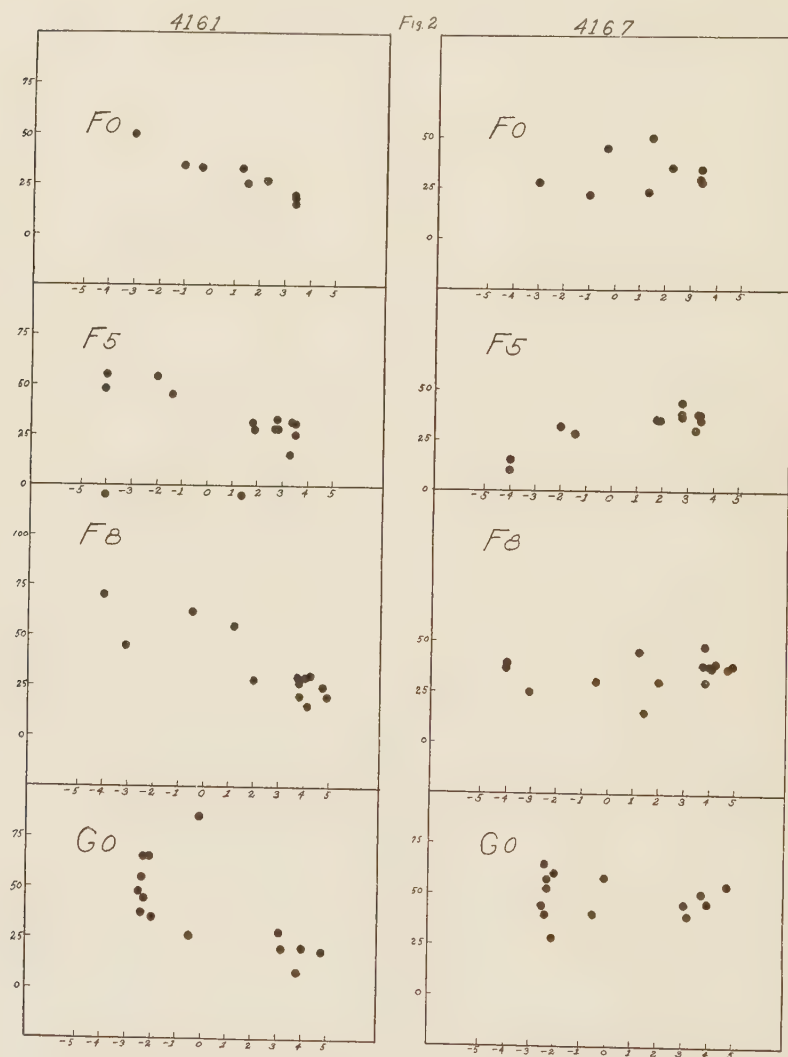


FIG. 2.—Intensities of $Ti\ II\ 4161$ and $Mg\ I\ 4167$ as a function of absolute magnitude.

As $Fe\ I\ 4071$ is little affected by differences in luminosity, changes in the ratio $4071/4077$ are due almost entirely to changes in the de-

nominator. Table XI gives smoothed values of intensity of $\lambda 4077$ and of the ratio $4071/4077$ for stars of absolute magnitude -2 and $+3.5$.

TABLE XI

DRAPER CLASS	INTENSITY				RATIO $4071/4077$	
	$\lambda 4077$		$\lambda 4071$		$M = -2$	$M = +3.5$
	$M = -2$	$M = +3.5$	$M = -2$	$M = +3.5$		
F0.....	0.57	0.33	0.32	0.32	0.56	0.97
F5.....	.61	.35	.43	.41	.70	1.17
F8.....	.82	.38	.50	.50	.61	1.32
G0.....	0.82	0.37	0.66	0.58	0.81	1.57

$Sr \text{ II } 4077$ shows a considerable increase in intensity for stars having $M = -2$, in passing toward later spectral classes. In the dwarfs, however, there is no appreciable change in intensity throughout the F-type subdivisions.

b) Ti II—Zr II 4161: Mg I 4167 (Fig. 2)

There is a definite luminosity effect for $\lambda 4161$ in all subdivisions of the F stars, the line tending to increase in strength with increasing luminosity. The intensity of $Mg \text{ I } 4167$ is relatively insensitive to

TABLE XII

DRAPER CLASS	INTENSITY				RATIO $4161/4167$	
	$Ti \text{ II—Zr II } 4161$		$Mg \text{ I } 4167$		$M = -2$	$M = +3.5$
	$M = -2$	$M = +3.5$	$M = -2$	$M = +3.5$		
F0.....	0.50	0.19	0.30	0.30	1.70	0.63
F5.....	.50	.26	.28	.33	1.80	.79
F8.....	.67	.27	.33	.39	2.00	.69
G0.....	0.45	0.18	0.44	0.40	1.00	0.45

differences in absolute magnitude. There is a possible tendency at F0 and at F8 for the line to be weaker in giants than in dwarfs. At F8, ρ Cassiopeiae again gives contradictory results. Table XII summarizes the behavior of the two lines individually and of their ratio.

The blended enhanced line $\lambda 4161$ passes through a maximum intensity at F8 both in the giants and in the dwarfs. $Mg\ I\ 4167$ shows

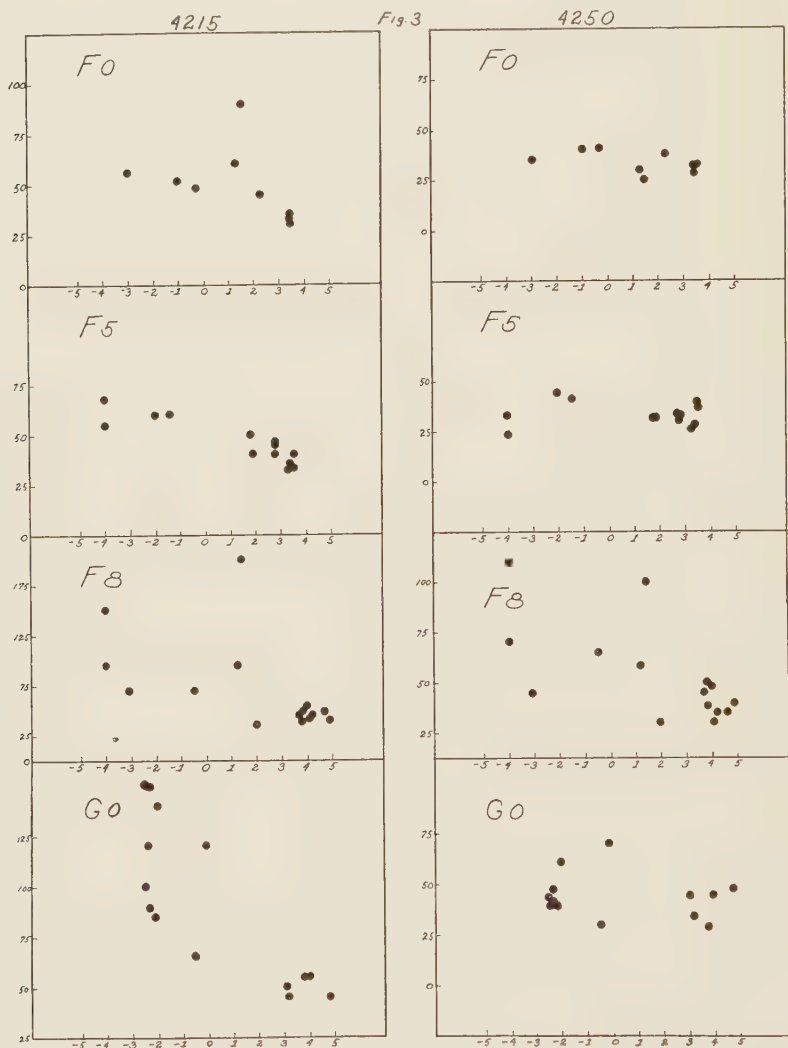


FIG. 3.—Intensities of $Sr\ II\ 4215$ and $Fe\ I\ 4250$ as a function of absolute magnitude.

little regular variation with temperature in the giants, although there seems to be a slight increase in intensity in passing to the later subdivisions.

c) $Sr\ II\ 4215:Fe\ I\ 4250$ (Fig. 3)

With the exception of a few "strontium dwarfs" there seems to be a good correlation of $\lambda\ 4215$ with absolute magnitude at Draper class Fo for stars absolutely fainter than $M = +1$. The variation of $Sr\ II\ 4215$ with absolute magnitude is also well defined at F5, F8, and Go. There is, however, a considerable scatter among the F8 and Go giants.

Table XIII gives the smoothed mean intensities and the intensity ratios of $\lambda\ 4215$ and $\lambda\ 4250$.

TABLE XIII

DRAPER CLASS	INTENSITY				RATIO 4215/4250	
	$Sr\ II\ 4215$		$Fe\ I\ 4250$			
	$M = -2$	$M = +3.5$	$M = -2$	$M = +3.5$	$M = -2$	$M = +3.5$
Fo.....	0.55	0.30	0.32	0.32	1.72	0.94
F5.....	0.60	.35	.32	.32	1.87	1.09
F8.....	0.90	.50	.65	.40	1.38	1.25
Go.....	1.00	0.55	0.42	0.35	2.38	1.31

TABLE XIV

DRAPER CLASS	INTENSITY				RATIO 4233/4235	
	$Fe\ II-Fe\ I\ 4233$		$Fe\ I\ 4235$			
	$M = -2$	$M = +3.5$	$M = -2$	$M = +3.5$	$M = -2$	$M = +3.5$
Fo.....	0.58	0.27	0.32	0.25	1.8	1.1
F5.....	.60	.28	.33	.33	1.8	0.9
F8.....	.75	.45	.65	.43	1.2	1.0
Go.....	0.60	0.40	0.53	0.40	1.1	1.0

$Sr\ II$ increases uniformly in intensity with the later types, for both the giants and the dwarfs. $Fe\ I\ 4250$ increases slightly in the same direction in the dwarfs, but there are no definite conclusions to be drawn from its behavior in the giants.

d) $Fe\ II-Fe\ I\ 4233:Fe\ I\ 4235$ (Fig. 4)

The intensities and the ratios of this pair are given in Table XIV.

λ 4233 passes through a maximum of intensity both in the giants and in the dwarfs at F8. As both lines of this pair tend to increase in

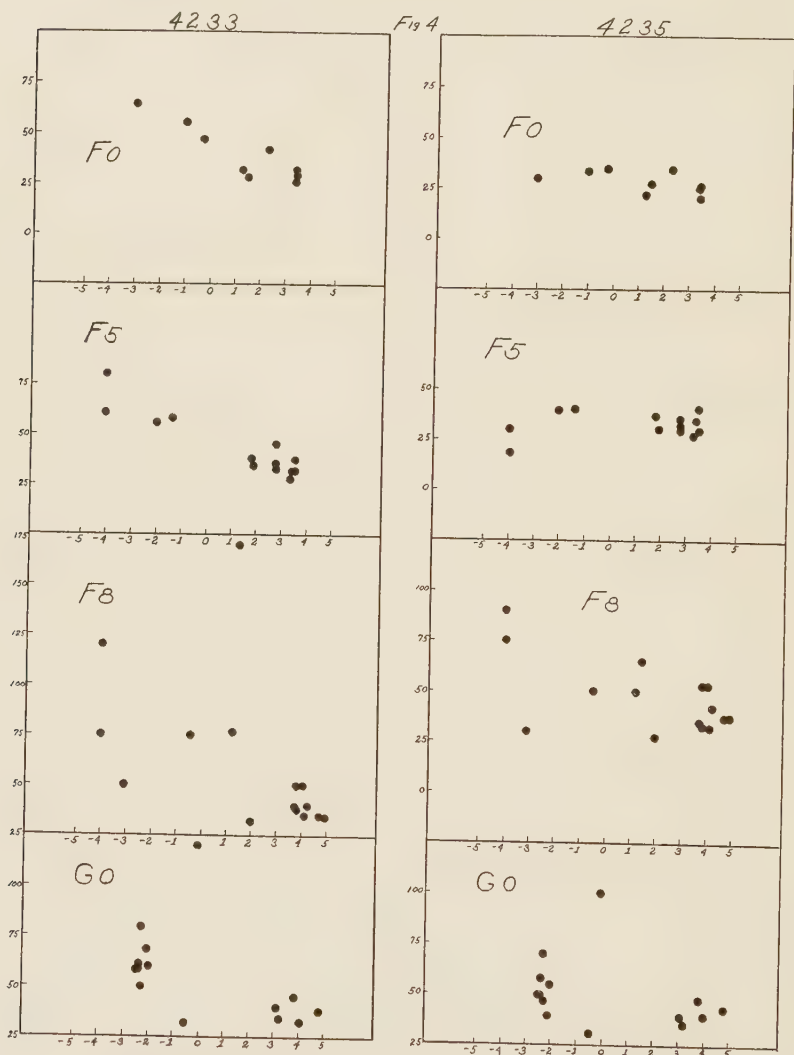


FIG. 4.—Intensities of $Fe\ II-Fe\ I\ 4233$ and $Fe\ I\ 4235$ as a function of absolute magnitude.

intensity with increasing luminosity, their ratio is not a very sensitive criterion for the determination of absolute magnitude except at type F5.

e) $Sc\ II\ 4246:Fe\ I\ 4250$ (Fig. 5)

The intensities and the ratios of the pair are given in Table XV.

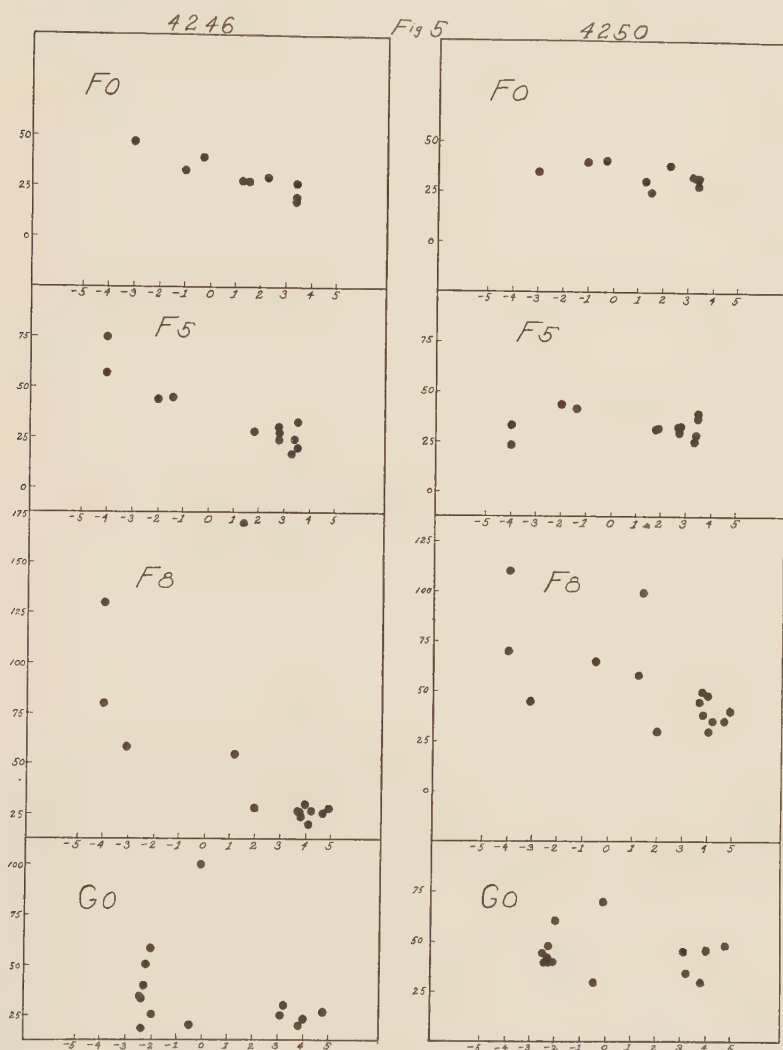


FIG. 5.—Intensities of $Sc\ II\ 4246$ and $Fe\ I\ 4250$ as a function of absolute magnitude.

$Sc\ II\ 4246$ appears to have a maximum at about F8, pronounced in giants but not appreciable in the dwarfs. The behavior of the iron line at $\lambda\ 4250$ has already been discussed. The ratio of these two

lines shows the greatest range at F5, and at Go it ceases to be appreciably influenced by luminosity.

We may summarize the spectral subdivisions in which each line ratio shows the greatest range with luminosity. This is shown in Table XVI.

TABLE XV

DRAPER CLASS	INTENSITY				RATIO 4246/4250	
	Sc II 4246		Fe I 4250		$M = -2$	$M = +3.5$
	$M = -2$	$M = +3.5$	$M = -2$	$M = +3.5$		
Fo.....	0.41	0.22	0.32	0.32	1.3	0.69
F5.....	.50	.22	.32	.32	1.6	.69
F8.....	.75	.32	.65	.40	1.1	.80
Go.....	0.38	0.28	0.42	0.35	0.90	0.80

TABLE XVI

Pair	Spectral Type Showing Greatest Effect (Draper)
4071/4077.....	F8, Go
4161/4167.....	F8
4215/4250.....	Go
4233/4235.....	F5
4246/4250.....	F5

V. THE BEHAVIOR OF *Ca* I 4226 AND *Fe* I 4045 AT F8 AND GO

9. The strongest line of *Fe* I in the observed spectral range at λ 4045 shows no very striking behavior with changes in luminosity in types earlier than F8, but at that type an actual change of sign in absolute-magnitude effect takes place on passing from the dwarfs to the giants. The same effect is clearly marked for the ultimate line of *Ca* I at λ 4226. The intensities of both lines are plotted against Mount Wilson spectroscopic absolute magnitudes in Figure 6. The intensity of *Ca* I 4226, which is 1.5 A at $M = +4.5$, decreases to 0.5 A at $M = +3.3$. No stars of intermediate luminosity are observed, and at the next observed point, $M = -2.0$, the intensity is 0.7 A. On passing to the giants of highest luminosity the line increases in intensity to 1.5 A at $M = -3.5$. The intensity is thus identical at $M = +4.5$ and $M = -3.5$, a range of 7 mag. in luminosity.

The same phenomenon is shown for $Fe\ I\ 4045$, except that the line never becomes as strong in the dwarfs as it is in the giants of the highest luminosity.

VI. THE INTERMEDIATE GIANTS OF TYPE G0

The behavior of $Ca\ I\ 4226$ and $Fe\ I\ 4045$ at G0 is shown in Figure 7. The same effect is present, although it is partially masked by three of the "intermediate giants," which are shown as open circles. The existence of this intermediate group of stars was shown statistically by Strömberg,¹⁰ and special reduction curves were used at

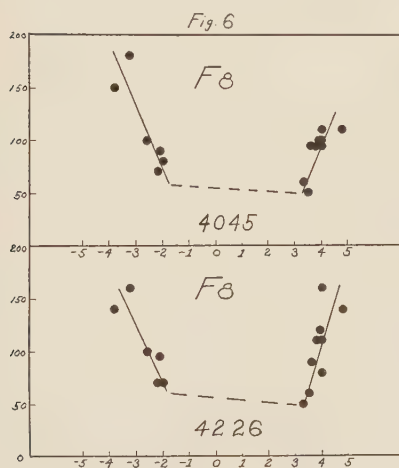


FIG. 6.—Intensities of $Fe\ I\ 4045$ and $Ca\ I\ 4226$ as a function of luminosity at type F8.

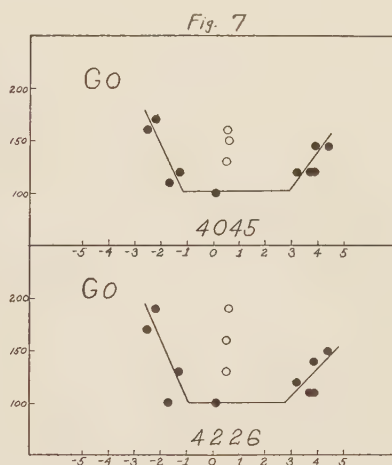


FIG. 7.—Intensities of $Fe\ I\ 4045$ and $Ca\ I\ 4226$ as a function of luminosity at type G0.

Mount Wilson for deriving their absolute magnitudes spectroscopically. It is of considerable importance to ascertain whether these three stars have luminosities definitely less than those of the normal giants. Table XVII gives a comparison of the three "intermediate giants" (group I) and the four giants proper (group II) at G0.

A comparison of the spectroscopic and trigonometric parallaxes of the three stars in group I leaves little doubt that the spectroscopic parallaxes are too large. In group I the mean of the spectroscopic parallaxes is $0''.030$ and the mean of the trigonometric parallaxes is $0''.004$; in group II the corresponding values are $0''.009$ and

¹⁰ *Ibid.*, 78, 178, 1933.

0".006. From the trigonometric data it seems fairly certain that the stars of group I are in general as luminous as those of group II. This is in agreement with the behavior of *Fe* 1 4045 and *Ca* 1 4226. The three stars of group I show spectroscopic evidence of considerably higher luminosity than Capella ($M = -0.5$ [trig.]). If these objects are moved over so that they agree with the normal giants, then the peculiar absolute-magnitude effect found at type F8 is well shown at Go also.

TABLE XVII
LUMINOSITIES OF Go GIANTS AND INTERMEDIATES

Star	<i>m</i>	<i>M</i> (M.W.)	π (Spec.)	π (Trig.)
Group I				
η Peg.....	3.1	+0.6	0".032	-0".002 $\pm$ 7
α UMa.....	3.5	+ .5	.025	+ .005 $\pm$ 6
β Lep.....	3.0	+0.5	0.032	+0.009 $\pm$ 6
Group II				
ϵ Leo.....	3.1	-1.3	0".011	+0".003 $\pm$ 6
β Dra.....	3.0	-1.7	.013	+ .002 $\pm$ 8
α Aqr.....	3.2	-2.2	.008	+ .004 $\pm$ 5
β Cam.....	4.2	-2.5	0.005	+0.014 $\pm$ 11

A possible explanation of the behavior of *Fe* 1 4045 and *Ca* 1 4226 may be suggested. The weakening of the lines along the dwarf sequence when passing toward higher luminosities may be the expected ionization effect. Neutral lines will be weakened with relation to singly ionized lines because of the decreased pressure in the stellar atmospheres. When the giant stars are reached, however, the atmospheres become so tremendously extensive that all lines are strengthened because of the additional amount of material effective in absorbing the spectral lines. This positive effect is so pronounced that it overcomes the negative effect which determines the behavior of the neutral lines in the dwarf sequence.

Table XVIII gives in successive columns: (1) the serial number; (2) the star's name; (3) the trigonometric parallax; (4) the probable

TABLE XVIII

No.	STAR	TRIGONOMETRIC			SPECTROSCOPIC ABSOLUTE MAGNITUDE				SPECTRAL TYPE		
		π	P.E.	Mag.	M.W.	Vic.	N.L.O.	Arc.	M.W.	Vic.	Arc.
Harvard Fo											
Width I:											
1.....	σ Boo	0".062	.006	3.4	3.2	.....	2.9	.....	F ₂	.....	.....
2.....	γ Vir(S)	89	7	3.4	2.8	3.2	2.9	.....	F ₀	F ₃	.....
3.....	γ Vir(N)	89	7	3.4	2.9	2.9	.....	.....	F ₀	F ₁	.....
4.....	η Aur	.....	.....	.....	2.5	.....	2.9	.....	F ₃	.....	.....
5.....	η Lep	50	7	2.3	2.8	.....	2.4	.....	F ₂	.....	.....
6.....	η Equ	22	6	1.5	-0.2	.....	.....	.....	F ₁	F ₁	F ₀ s
7.....	β Cor	33	5	1.3	1.1	-0.3	2.1	1.7	A ₇ s	F ₀	A ₆ s
8.....	20 CVn	10	6	-0.3	2.0	0.8	-1.4	.....	F ₅	F ₃	.....
9.....	ν Her	2	5	-1.0	2.0	1.4	.....	.....	F ₁	F ₃	.....
10.....	α Lep	—	3	6	-3.0	-0.9	-1.6	-0.8	F ₃	F ₄	.....
Width II:											
11.....	η Crv	56	8	3.2	2.9	.....	3.0	.....	F ₂	.....	.....
12.....	ρ Gem	57	6	3.0	2.4	2.4	2.0	2.4	A ₈ s	A ₈	A ₉ n
13.....	γ And	48	7	3.0	2.7	2.6	2.8	.....	F ₂	F ₁	.....
14.....	18 Boo	.....	.....	.....	3.0	.....	2.5	2.3	F ₁	.....	F ₈ n
15.....	ω Oph	33	8	2.2	1.2	.....	1.5	.....	A ₆ s	.....	.....
16.....	30 LMi	.....	.....	.....	2.1	2.0	2.2	.....	F ₃	F ₁	.....
17.....	μ Cet	31	8	1.8	2.2	.....	2.3	.....	F ₄	.....	.....
18.....	γ Cap	28	7	1.0	1.8	.....	.....	.....	F ₂	.....	.....
19.....	22 And	-0.006	.010	-0.4	0.2	.....	1.9	.....	cF ₂	.....	.....
Width III:											
20.....	16 Lib	0".040	.005	2.6	1.8	.....	2.1	2.1	A ₉ n	.....	F ₁ s
21.....	38 Gem	39	6	2.6	2.1	.....	2.8	2.0	A ₇ n	.....	A ₆ n
22.....	τ Cyg	50	5	2.3	2.7	2.0	2.2	2.4	F ₀	F ₁ n	F ₀ n
23.....	δ Aql	54	6	2.1	1.9	.....	2.4	.....	A ₅ n	.....	.....
24.....	ϕ Gem	16	6	1.0	2.2	0.7	1.3	2.1	F ₁	F ₁	F ₁ sn
25.....	ζ Leo	10	6	-1.4	1.3	0.6	0.3	2.2	F ₀	F ₁	F ₂ sn
Width IV:											
26.....	δ Gem	60	5	2.4	2.2	.....	1.8	.....	A ₈ n	.....	.....
27.....	78 UMa	30	10	2.3	1.8	.....	2.3	.....	A ₆ n	.....	.....
28.....	25 CVn	27	6	2.1	2.2	.....	1.5	.....	A ₃ n	.....	.....
29.....	23 UMa	37	6	1.6	1.9	.....	2.2	.....	A ₄ n	.....	.....
30.....	γ Boo	.....	.....	.....	1.6	.....	1.9	.....	A ₅ n	.....	.....
31.....	γ Her	0.015	.010	-0.3	1.5	.....	1.4	.....	A ₆ n	.....	.....
Harvard F ₂											
Width II:											
32.....	81 Leo	.....	.....	.....	3.0	.....	2.5	.....	F ₂	.....	.....
33.....	53 Vir	0".013	.011	0.7	3.0	.....	3.4	.....	F ₅	.....	.....
34.....	π Sag	0.015	.013	-1.1	-0.5	.....	-0.7	.....	cF ₃	.....	.....

TABLE XVIII—*Continued*

No.	STAR	TRIGONOMETRIC			SPECTROSCOPIC ABSOLUTE MAGNITUDE				SPECTRAL TYPE		
		π	P.E.	Mag.	M.W.	Vic.	N.L.O.	Arc.	M.W.	Vic.	Arc.
Harvard F ₅											
Width I:											
35.....	40 Leo	0".051	.011	3.5	3.3	.....	3.4	.....	F ₅	.....	.....
36.....	δ Equ	0.060	.004	3.5	4.0	4.0	4.1	3.2	F ₃	F ₆	F _{5n}
37.....	ι Peg	0".077	.006	3.4	3.6	3.4	3.5	3.2	F ₃	F ₄	F _{5n}
38.....	γ Ser	78	7	3.3	3.3	4.2	4.2	.....	F ₅	F ₆	.....
39.....	110 Her	51	7	2.8	3.1	3.9	3.2	.....	F ₃	F ₄	.....
40.....	ξ Peg	49	7	2.8	3.8	3.2	3.3	2.4	F ₃	F ₅	F _{5s}
41.....	α CMn	291	4	2.8	3.1	3.0	3.1	.....	F ₃	F ₅	.....
42.....	ω And	24	6	1.9	2.8	3.2	2.8	.....	F ₂	F ₃	.....
43.....	35 Dra	22	7	1.8	2.9	.....	3.4	.....	F ₅	.....	.....
44.....	35 Cyg	.....	.....	.....	-1.3	-2.7	-1.2	.....	cF ₅	F ₇	.....
45.....	41 Cyg	4	5	-1.4	-0.9	-0.8	-1.0	.....	cF ₄	F ₅	F _{5n}
46.....	89 Her	.....	.....	.....	-1.5	.....	-2.5	.....	cF ₅	.....	.....
47.....	α Per	9	4	-2.0	-1.2	-0.6	-1.5	.....	cF ₄	F ₄	.....
48.....	ϕ Cas	—	6	5	-4.0	-2.8	-3.2	.....	cF ₇	.....	.....
49.....	ϵ Aur	2	7	-4.0	-1.7	-2.8	-2.8	.....	cF ₂	F ₂	.....
Width II:											
50.....	B.S. 3579	72	6	3.4	3.3	3.4	3.3	.....	F ₂	F ₅	.....
51.....	τ Boo	61	7	3.4	3.5	4.2	2.9	.....	F ₆	F ₇	.....
52.....	ι Vir	42	7	2.3	3.0	.....	2.3	.....	F ₅	.....	.....
53.....	μ Vir	45	5	2.2	2.7	2.0	2.5	.....	F ₃	F ₃	.....
54.....	β Cas	71	7	1.7	2.2	1.7	1.7	.....	F ₂	F ₂	.....
55.....	β Del	27	6	0.9	2.6	1.9	1.9	2.4	F ₃	F ₃	F _{2n}
56.....	ν Per	16	7	-0.1	-1.0	0.0	0.7	.....	cF ₄	F ₃	.....
Width III:											
57.....	α Tri	51	8	2.1	2.4	1.7	1.4	.....	F ₂	F ₂	.....
58.....	ξ Gem	48	7	1.8	2.2	0.8	1.9	2.4	F ₃	F ₅	F _{2n}
59.....	κ Peg	0.024	.005	1.2	3.0	2.4	2.8	2.4	F ₂	F ₂	Agn
Harvard F ₈											
Width I:											
60.....	η Cas	0".182	.005	4.9	4.8	5.2	4.4	3.6	F ₉	F ₈	F _{7n}
61.....	χ' Ori	.104	.006	4.7	4.0	4.6	4.4	.....	F ₉	G ₁	.....
62.....	γ Lep	.122	.004	4.2	3.8	.....	3.9	.....	F ₆	.....	.....
63.....	χ Dra	.119	.008	4.1	4.0	4.3	4.0	.....	F ₅	F ₅	.....
64.....	BS 244	.064	.010	4.0	3.9	.....	3.7	.....	F ₈	.....	.....
65.....	π^3 Ori	.128	.005	3.8	3.5	4.0	3.5	.....	F ₅	F ₅	.....
66.....	β Vir	.101	.007	3.8	4.0	3.7	3.5	.....	F ₈	F ₈	.....
67.....	θ Per	.078	.005	3.7	3.6	.....	4.1	.....	F ₅	F ₈	.....
68.....	θ UMa	0.056	.006	2.0	3.3	2.4	2.9	.....	F ₄	F ₇	.....

TABLE XVIII—*Continued*

No.	STAR	TRIGONOMETRIC			SPECTROSCOPIC ABSOLUTE MAGNITUDE				SPECTRAL TYPE		
		π	P.E.	Mag.	M.W.	Vic.	N.L.O.	Arc.	M.W.	Vic.	Arc.
Harvard F8—Continued											
Width I:											
69.....	ρ Cas	0".022	.005	1.4	-3.2	.....	-3.5	.....	cGo	.....	.....
70.....	ι Pup	.023	.009	1.2	-2.6	.....	.....	.....	cG ₂	.....	.....
71.....	45 Dra	.008	.006	-0.5	-2.0	.....	-2.9	.....	cF8	.....	.....
72.....	α UMa	.003	.004	-3.1	-2.2	-2.2	-2.2	.....	cF7	F7	.....
73.....	δ CMa	— .019	.009	-4.0	-3.8	.....	-3.1	.....	G ₃	.....	.....
74.....	γ Cyg	— .004	.007	-4.0	-2.1	-3.2	-3.3	.....	cF7	F7	.....
Width II:											
75.....	θ Boo	.068	.007	3.2	3.3	3.6	3.3	.....	F6	F6	.....
76.....	θ Dra	.046	.005	2.4	3.0	2.8	3.2	.....	F7	F7	.....
77.....	ϵ Hyd	0.025	.006	0.5	2.7	.....	.....	.....	F8	.....	.....
Harvard Go											
Width I:											
78.....	Sun	.....	.....	4.8	.....	.....	.....	.....	.....	.....	.....
79.....	λ Aur	0".068	.005	4.0	4.4	5.6	4.4	.....	Go	G ₁	.....
80.....	ι Per	.085	.004	3.8	3.9	4.3	4.4	.....	G ₁	G ₁	.....
81.....	ζ Her	0.110	.005	3.2	3.7	3.2	3.0	.....	Go	Go	.....
82.....	η Boo	.....	.....	.....	3.2	3.4	2.5	.....	F7	Go	.....
83.....	ν And	0".061	.007	3.1	3.7	4.0	3.8	.....	Go	F8	.....
84.....	β Cam	14	11	-0.1	-2.5	-3.0	-3.2	.....	cG ₂	Go	.....
85.....	α Aur	71	4	-0.5	0.1	1.1	0.1	.....	G ₁	G ₁	.....
86.....	σ UMa	5	6	-2.0	0.5	.....	-0.5	.....	G ₁	.....	.....
87.....	43 Gem	6	6	-2.1	.....	-3.2	-3.3	.....	.....	Go	.....
88.....	β Lep	9	6	-2.3	0.5	.....	-0.6	.....	G ₁	.....	.....
89.....	ϵ Leo	2	8	-2.4	-1.3	.....	-0.9	.....	cG ₃	.....	.....
90.....	β Dra	3	6	-2.5	-1.7	-2.0	.....	.....	cG ₂	Go	.....
Width II:											
91.....	α Aqr	4	5	-2.3	-2.2	-1.8	-2.5	.....	cG ₁	F ₉	.....
92.....	η Peg	-0.002	.007	-2.4	0.6	0.4	-0.5	.....	G ₂	G ₁	.....

error of the trigonometric parallax; (5) the absolute magnitude derived from the trigonometric parallax; (6), (7), (8), and (9) the spectroscopic parallaxes determined at Mount Wilson, Victoria, the Norman Lockyer Observatory, and Arcetri; (10), (11), and (12) the spectral classes determined at Mount Wilson, Victoria, and Arcetri.

Both Tables XVIII and XIX group the stars according to Har-

TABLE XIX—Continued

No.	Star	K	H δ	λ 4045	λ 4063	λ 4071	λ 4077	λ 4132	λ 4161	λ 4167	λ 4215	λ 4226	λ 4246	λ 4250	λ 4233	λ 4235
Harvard Fo—Continued																
Width IV:																
26.....	δ Gem	5.2	9.2	0.35	0.33	0.14	0.55	0.19	.....	.....	.....	.....	.....	.....	.....	.....
27.....	78 UMa	6.5	5.5	.40	.26	.31	.59	.23	.....	.....	.....	.....	.....	.....	.....	.....
28.....	25 CVn	4.2	8.4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
29.....	23 UMa	4.7	7.0	.31	.25	.....	.53	.....	.....	.....	.....	.....	.....	.....	.....	.....
30.....	γ Boo	6.3	11.5	.43	.44	.40	.74	.....	.....	.....	.....	.....	.....	.....	.....	.....
31.....	γ Her	5.7	8.9	0.31	0.23	0.12	0.53	0.10	.....	.....	.....	.....	.....	.....	.....	.....
Harvard F2																
Width II:																
32.....	81 Leo	5.5	.....	0.62	0.42	0.35	0.45	0.22	0.34	0.32	0.45	0.70	0.32	0.36	0.42	0.35
33.....	53 Vir	6.2	.....	.85	.42	.40	.42	.43	.30	.35	.47	.75	.22	.40	.42	.36
34.....	π Sag	6.0	4.3	0.60	0.58	0.35	0.50	0.39	0.38	0.34	0.44	0.50	0.38	0.36	0.46	0.33
Harvard F5																
Width I:																
35.....	40 Leo	3.7	.....	0.77	0.55	0.40	0.38	0.35	0.32	0.38	0.40	0.70	0.33	0.39	bl	0.41
36.....	δ Equ	4.3	.....	.77	.72	.42	.32	.20	.26	.35	.33	.80	.20	.37	.32	.29
37.....	ι Peg	5.6	3.0	.60	.50	.40	.38	.26	.32	.38	.36	.55	.24	.28	.32	.34
38.....	γ Ser	6.0	3.3	.66	.71	.40	.32	.21	.15	.30	.32	.65	.17	.26	.28	.27
39.....	110 Her	6.3	4.4	0.64	0.55	0.46	0.35	0.31	0.28	0.38	0.40	0.60	0.31	0.33	0.33	0.30

TABLE XIX—Continued

[illegible]

TABLE XIX—Continued

No.	Star	K	H δ	λ 4045	λ 4063	λ 4071	λ 4077	λ 4132	λ 4161	λ 4167	λ 4215	λ 4226	λ 4246	λ 4250	λ 4233	λ 4235
Harvard F8																
Width I:																
60	η Cas	6.0	.....	1.1	0.97	0.67	0.32	0.75	0.20	0.38	0.40	1.4	0.28	0.40	0.34	0.37
61	χ^1 Ori	6.6	.....	1.1	0.90	0.85	0.35	0.75	0.24	.37	0.48	1.6	0.26	0.35	0.35	.37
62	γ Lep	5.5	.....	0.95	0.73	0.55	0.46	0.50	0.30	.39	0.45	1.1	0.27	0.35	0.40	.42
63	χ Dra	6.6	3.5	1.0	0.75	0.52	0.39	0.36	0.15	.37	0.42	1.1	0.20	0.30	0.35	.32
64	BS 244	.....	.....	1.0	0.83	0.60	0.40	0.40	0.29	.38	0.55	1.2	0.30	0.48	0.50	.53
65	π^3 Ori	6.2	4.3	0.50	0.45	0.40	0.38	0.25	0.20	.30	0.38	0.60	0.25	0.38	0.38	.33
66	β Vir	7.7	3.1	0.95	0.76	0.60	0.47	0.46	0.27	.48	0.48	0.80	0.26	0.50	0.50	.53
67	θ Per	.....	.....	0.95	0.90	0.60	0.45	0.60	0.29	.38	0.45	0.90	0.27	0.45	0.40	.35
68	θ UMa	6.7	1.8	0.60	0.45	0.40	0.35	0.29	0.28	.30	0.35	0.50	0.28	0.30	0.32	.27
69	ρ Cas	9.0	.....	1.8	1.6	1.3	2.2	1.0	1.2	.15	2.0	1.6	1.9	1.0	1.7	.65
70	η Pup	3.4	.....	1.0	0.75	0.50	0.90	0.68	0.55	.45	0.95	1.0	0.55	0.58	0.77	.50
71	45 Dra	7.3	.....	0.80	0.70	0.40	0.75	0.62	0.62	.30	0.70	0.70	0.65	0.65	0.75	.50
72	α UMi	7.3	3.3	0.70	0.50	0.38	0.65	0.44	0.45	.25	0.70	0.70	0.58	0.45	0.50	.30
73	δ CMa	9.0	1.7	1.5	1.4	0.90	1.9	1.1	1.2	.37	1.5	1.4	1.3	1.1	1.2	.90
74	γ Cyg	7.6	.....	0.90	0.85	0.45	0.85	0.64	0.70	.39	0.95	0.95	0.80	0.70	0.75	.75
Width II:																
75	θ Boo	5.5	.....	0.90	0.65	0.50	0.38	0.33	0.34	.47	0.45	1.20	0.30	0.38	0.42	.40
76	θ Dra	5.0	.....	0.85	0.60	0.50	0.36	0.39	0.33	.47	0.52	0.85	0.28	0.42	0.45	.40
77	ϵ Hyd	.....	.....	0.90	0.75	0.50	0.37	0.43	0.12	.37	0.60	1.20	0.15	0.30	0.38	.35

TABLE XIX—Continued

No.	Star	K	H δ	λ 4045	λ 4063	λ 4071	λ 4077	λ 4132	λ 4161	λ 4167	λ 4215	λ 4226	λ 4246	λ 4250	λ 4233	λ 4235
Harvard Go																
<i>Width I:</i>																
78.....	Sun	7.4	1.0	1.4	1.0	0.95	0.45	0.73	0.18	0.55	0.45	1.8	0.27	0.48	0.38	0.43
79.....	λ Aur	6.9	1.6	1.4	1.05	.80	.35	.40	.20	.40	.55	1.5	.23	.45	.33	.40
80.....	ϵ Per	7.2	2.5	1.4	0.92	.66	.50	.46	.08	.51	.55	1.4	.20	.29	.45	.48
81.....	ζ Her	6.9	1.6	1.2	0.80	0.65	0.37	0.31	0.20	0.39	0.46	1.1	0.30	0.34	0.34	0.36
82.....	η Boo	6.9	3.2	1.2	0.65	0.67	0.37	0.43	0.25	0.65	0.80	1.2	0.18	0.35	0.55	0.60
83.....	ν And	6.6	2.5	1.2	0.77	0.65	0.38	.55	.28	.45	.51	1.1	0.25	.45	0.40	0.39
84.....	β Cam	6.6	.....	1.6	1.1	0.70	1.0	.80	.85	.58	1.2	1.7	1.0	.70	1.2	1.0
85.....	α Aur	6.6	1.4	1.0	0.77	0.68	0.55	.40	.26	.40	0.66	1.0	0.20	.29	0.32	0.31
86.....	σ UMa	7.3	.....	1.6	1.2	1.0	0.94	.92	.35	.60	1.4	1.6	0.25	.61	0.60	0.55
87.....	43 Gem	7.4	.....	1.1	0.65	0.58	0.00	.50	.65	.28	0.85	1.0	0.58	.40	0.68	0.40
88.....	β Lep	7.7	.....	1.3	0.81	0.65	0.68	.57	.45	.57	0.90	1.3	0.40	.48	0.50	0.47
89.....	ϵ Leo	7.7	.....	1.2	0.81	0.65	0.80	.67	.37	.40	1.20	1.3	0.33	.40	0.58	0.50
90.....	β Dra	6.0	1.2	1.1	0.79	0.67	0.90	.50	.48	.44	1.00	1.0	0.34	.44	0.58	0.50
<i>Width II:</i>																
91.....	α Aqr	8.1	.....	1.7	1.05	0.88	1.5	.76	.65	.53	1.5	1.9	0.50	.42	0.80	0.70
92.....	η Peg	8.1	.....	1.5	0.88	0.92	1.1	0.60	0.54	0.65	1.5	1.9	0.18	0.40	0.60	0.58

ward spectral classes; within each class the stars are arranged according to line width and within each group according to increasing luminosity determined from the trigonometric parallaxes.

Table XIX gives in successive columns the serial number; the star's name; the intensities in angstroms of total absorption of *Ca II K*, *H δ* , *Fe I 4045*, *Fe I 4063*, *Fe I 4071*, *Sr II 4077*, *Fe I 4132*, *Zr II—Ti II 4161*, *Mg I 4167*, *Sr II 4215*, *Ca I 4226*, *Sc II 4246*, *Fe I 4250*, *Fe II—Fe I 4233*, and *Fe I 4235*.

In addition to the topics discussed in the present paper, a number of other phases of the F-type spectra are under investigation. A preliminary report on some of these has already been published.¹¹ These include investigations of the composite stars, the behavior of the *CH* molecule with respect to spectral class and luminosity, and a general discussion of the question of the classification of the F stars. It is expected that the greater part of the work will be completed in a short time.

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